AD NO. ____________________________
DTC PROJECT NO. 8-CO-160-UXO-021
REPORT NO. ATC-8726

STANDARDIZED

UXO TECHNOLOGY DEMONSTRATION SITE

MINE GRID SCORING RECORD NO. 126

SITE LOCATION:
ABERDEEN PROVING GROUND

DEMONSTRATOR:
WITTEN TECHNOLOGIES INC.
295 HUNTINGTON AVENUE
BOSTON, MA 02115

PREPARED BY:
U.S. ARMY ABERDEEN TEST CENTER
ABERDEEN PROVING GROUND, MD 21005-5059

DECEMBER 2003

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Prepared for:
U.S. ARMY ENVIRONMENTAL CENTER
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14. ABSTRACT

This scoring record documents the efforts of Witten Technologies Inc. utilizing the APG Standardized UXO Technology Demonstration Site Mine Grid. The scoring record was written by Larry Overbay utilizing methodology coordinated with the Standardized UXO Technology Demonstration Site Program Scoring Committee. Organizations on the committee include the U.S. Army Corps of Engineers, the Environmental Security Technology Certification Program, the Strategic Environmental Research and Development Program, the Institute for Defense Analysis, the U.S. Army Environmental Center, and the U.S. Army Aberdeen Test Center.

15. SUBJECT TERMS

Witten Technologies Inc., UXO, Standardized Site, APG, Standardized UXO Technology Demonstration Site Program, Mine Grid.

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SECTION 1. GENERAL INFORMATION

1.1 BACKGROUND

Technologies under development for the detection and discrimination of unexploded ordnance (UXO) require testing so that their performance can be characterized. To that end, Standardized Test Sites have been developed at Aberdeen Proving Ground (APG), Maryland and U.S. Army Yuma Proving Ground (YPG), Arizona. These test sites provide a diversity of geology, climate, terrain, and weather as well as diversity in ordnance and clutter. Testing at these sites is independently administered and analyzed by the government for the purposes of characterizing technologies, tracking performance with system development, comparing performance of different systems, and comparing performance in different environments.

The Standardized UXO Technology Demonstration Site Program is a multi-agency program spearheaded by the U.S. Army Environmental Center (AEC). The U.S. Army Aberdeen Test Center (ATC) and the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) provide programmatic support. The program is being funded and supported by the Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP) and the Army Environmental Quality Technology Program (EQT).

1.2 SCORING OBJECTIVES

The objective in the Standardized UXO Technology Demonstration Site Program is to evaluate the detection and discrimination capabilities of a given technology under various field and soil conditions. Inert munitions and clutter items are positioned in various orientations and depths in the ground.

The evaluation objectives are as follows:

a. To determine detection and discrimination effectiveness under realistic scenarios that vary targets, geology, clutter, topography, and vegetation.

b. To determine cost, time, and manpower requirements to operate the technology.

c. To determine demonstrator's ability to analyze survey data in a timely manner and provide prioritized "Target Lists" with associated confidence levels.

d. To provide independent site management to enable the collection of high quality, ground-truth, geo-referenced data for post-demonstration analysis.

1.2.1 Scoring Methodology

a. The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver-operating characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}), and those that do not correspond to any known item, termed background alarms.

b. The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the Mine Grid RESPONSE STAGE, the demonstrator provides the scoring committee with a target response from each and every grid square along with a noise level below which target responses are deemed insufficient to warrant further investigation. This list is generated with minimal processing and, since a value is provided for every grid square, will include signals both above and below the system noise level.

c. The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such and to reject clutter. For the Mine Grid DISCRIMINATION STAGE, the demonstrator provides the scoring committee with the output of the algorithms applied in the discrimination-stage processing for each grid square. The values in this list are prioritized based on the demonstrator's determination that a grid square is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For digital signal processing, priority ranking is based on algorithm output. For other discrimination approaches, priority ranking is based on human (subjective) judgment. The demonstrator also specifies the threshold in the prioritized ranking that provides optimum performance, (i.e. that is expected to retain all detected ordnance and rejects the maximum amount of clutter).

d. The demonstrator is also scored on EFFICIENCY and REJECTION RATIO, which measures the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from nonordnance items. EFFICIENCY measures the fraction of detected ordnance retained after discrimination, while the REJECTION RATIO measures the fraction of false alarms rejected. Both measures are defined relative to performance at the demonstrator-supplied level below which all responses are considered noise, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

e. All scoring factors are generated utilizing the Standardized UXO Probability and Plot Program, version 3.1.1.

1.2.2 Scoring Factors

Factors to be measured and evaluated as part of this demonstration include:

a. Response Stage ROC Curves:

(1) Probability of Detection (P_d^{res}).

(2) Probability of False Positive (P_{fp}^{res}).

(3) Background Alarm Rate (BAR^{res}) or Probability of Background Alarm (P_{BA}^{res}).

b. Discrimination Stage ROC Curves:

(1) Probability of Detection (P_d^{disc}).

(2) Probability of False Positive (P_{fp}^{disc}).

(3) Background Alarm Rate (BAR^{disc}) or Probability of Background Alarm (P_{BA}^{disc}).

c. Metrics:

(1) Efficiency (E).

(2) False Positive Rejection Rate (R_{fp}).

(3) Background Alarm Rejection Rate (R_{BA}).

d. Other:

(1) Location accuracy.

(2) Equipment setup, calibration time and corresponding man-hour requirements.

(3) Survey time and corresponding man-hour requirements.

(4) Re-acquisition/resurvey time and man-hour requirements (if any).

(5) Downtime due to system malfunctions and maintenance requirements.

1.3 STANDARDIZED INERT MINE TARGETS

The standard inert mine targets emplaced in the test area are listed in Table 1. Standardized targets are members of a set of specific ordnance items that have identical properties to all other items in the set (caliber, configuration, size, weight, aspect ratio, material, filler, magnetic remanence, and nomenclature).

TABLE 1. STANDARDIZED INERT MINE TARGETS

Type
TM-62 large metal mines
AT VS 1.6 low metal mines
AP VS 5.0 low metal mines
AP M14 low metal mines

SECTION 2. DEMONSTRATION

2.1 DEMONSTRATOR INFORMATION

2.1.1 Demonstrator POC and Address

Point of contact: Michael Oristag
(617) 236-0019

Address: Witten Technologies, Inc.
295 Huntington Avenue
Boston, MA 02115
(617) 236-0019

2.1.2 System Description (Provided by Demonstrator)

The CART Imaging System is a new synthetic-aperture radar system designed for 3D underground imaging (fig. 1). The radar in the standard 200 MHz CART is a down-looking, ultra-wideband impulse radar, with a pulse spectrum from about 50 to 400 MHz. (A proto-type 400 MHz CART is available with pulse spectrum from about 150 to 650 MHz.)

Figure 1. Demonstrator's system.

The CART uses nine transmitters and eight receivers in two parallel rows to create an equivalent 16-channel (bi-static) ground-penetrating radar (GPR) array. Spacing between channels in the normal array is about 5 inches, so the ground swath covered by the array is about

6.25 feet wide (1.9 m). The physical antennas are bowties (linear dipoles) aligned along the direction of motion. The system can fire and collect all 16 channels once every 4 inches (measured along the direction of motion), while moving at speeds up to 1500 ft/hr (475 m/hr).

To record positions, the CART uses a surveying instrument called a laser theodolite (also called a Geodimeter or total station). Positioning is accurate to a fraction of an inch over a range of several thousand feet, provided there is line of sight between a reflecting prism mounted on the radar unit and a base station. The positioning system allows the radar to move in arbitrary patterns over the ground to collect data on an irregular grid. Special algorithms re-grid the data and perform synthetic-aperture focusing in the two horizontal (cross-range) directions to create a 3D synthetic-aperture radar (SAR) image.

2.1.3 Data Processing Description (Provided by Demonstrator)

a. The first step in data acquisition was to establish a position for the base station of the survey Geodimeter. The position must have good lines of sight over the area surveyed. The parameters for the radar acquisition were then set:

(1) Time sampling: typically, 0.1 to 0.5 ns.

(2) Total recording time : typically, 40 to 120 ns.

(3) Inline sampling interval (along the direction of motion): typically, 2 to 4 inches.

(4) Position tracking interval: typically, every 4 to 6 feet.

Radar data acquisition then proceeds as the vehicle with the CART system drives over the site in an arbitrary pattern and the Geodimeter system records its position at the specified intervals. Data collection of a single profile is usually stopped after the vehicle proceeds a given distance, usually about 100 to 300 feet; and a new profile is started. This process repeats itself until the whole area is covered. In certain applications, where the polarization of the radar antennas could be important, the area will be covered a second time with the vehicle proceeding along profiles that are approximately perpendicular to the initial ones.

To provide a reference grid for the underground images, surface features, such as curb lines, manhole covers and trees, are surveyed when the radar data are collected and superimposed on the image. The final images, usually presented as horizontal slices through the ground at different depths, are provided electronically in various formats-images (.jpg), movies (.mov, .avi), or computer-aided design (CAD) (.dwg, .dng).

b. Radar data are first processed to clean up the raw traces; this involves:

(1) Aligning data to a common zero-time reference.

(2) Filtering to compensate for variations in antenna responses.

(3) Filtering to remove unwanted signal reverberations within the CART.

Special algorithms merge the positioning data (in a local coordinate system) and the radargrams, which are interpolated onto a uniform grid for synthetic-aperture focusing. Coherency analysis determines the best velocity for focusing energy in the subsurface. Focused (migrated) images are then produced in horizontal planes going down from the surface, usually in 1-inch depth increments.

Features are extracted from the images by software that is guided by a human interpreter. Standard routines are used to look for coherent events (linear features or areas of high intensity) in the image. Radar images can be superimposed or correlated with other image data or maps to aid the interpretation.

2.1.4 Data Submission Format

Data were submitted for scoring in accordance with data submission protocols outlined in the Standardized UXO Technology Demonstration Site Handbook (app E, ref 1). These data are not included in this report in order to protect ground truth information.

2.1.5 Demonstrator Quality Assurance (QA) and Quality Control (QA) (Provided by Demonstrator)

Quality Control and Quality Assurance are based on a team approach, with external reviewers. A team leader is designated for each survey. This will usually be the senior engineer for the survey or the operations manager. The team will first meet with local staff well in advance of any survey to review all logistical issues related to the survey, including on-site safety. A plan and schedule are then made for getting equipment to and from the site and for each day's operations. On-site, the survey crew proceeds through a checklist before data collection starts (including checking position of Geodimeter for line of sight and warm-up test of radar). After the first profile is collected, data are loaded and reviewed on site with our field QC software package. Simple coherency analysis is performed to determine depth of penetration in soil, and acquisition parameters are adjusted (sampling rate and time window).

After a series of profiles (usually, three or four) data are merged on site to ensure proper spacing of profiles and performance of the positioning system. Data from each day survey will be downloaded to the data-processing server in Austin or Boston and reviewed by the data processing manager and the scientific support staff. The data processing manager is responsible for the overall QC review of the processing.

2.1.6 Additional Records

None.

2.2 APG SITE INFORMATION

2.2.1 Location

The APG Standardized Test Site is located within a secured range area of the Aberdeen Area of APG. The Aberdeen Area of APG is located approximately 30 miles northeast of Baltimore at the northern end of the Chesapeake Bay. The Standardized Test Site encompasses 17 acres of upland and lowland flats, woods and wetlands.

2.2.2 Soil Type

According to the soils survey conducted for the entire area of APG in 1998, the test site consists primarily of Elkton Series type soil (ref 2). The Elkton Series consist of very deep, slowly permeable, poorly drained soils. These soils formed in silty aeolin sediments and the underlying loamy alluvial and marine sediments. They are on upland and lowland flats and in depressions of the Mid-Atlantic Coastal Plain. Slopes range from 0 to 2 percent.

ERDC conducted a site-specific analysis in May of 2002 (ref 3). The results basically matched the soil survey mentioned above. Seventy percent of the samples taken were classified as silty loam. The majority (77 percent) of the soil samples had a measured water content between 15 and 30 percent with the water content decreasing slightly with depth.

For more details concerning the soil properties at the APG test site, go to http://aec.army.mil/usaec/technology/uxo-soils.pdf on the web to view the entire soils description report.

2.2.3 Test Areas

A description of the test site areas at APG is included in Table 2.

TABLE 2. TEST SITE AREAS

Area	Description
Calibration Grid	Contains 14 standard ordnance items buried in six positions at various angles and depths to allow demonstrator to calibrate their equipment.
Blind Test Grid	Contains 400 grid cells in a 0.2-hectare (0.5 acre) site. The center of each grid cell contains ordnance, clutter or nothing.
Mine Test Grid	Contains 100 grid cells in a 0.02-hectare (0.05-acre) site. The center of each grid cell will contain a mine, clutter or nothing.

SECTION 3. FIELD DATA

3.1 DATE OF FIELD ACTIVITIES (2 TO 3 DECEMBER 2002)

3.2 AREAS TESTED/NUMBER OF HOURS

Areas tested and number of hours operated at each site are summarized in Table 3.

TABLE 3. AREAS TESTED AND NUMBER OF HOURS

Area	Number of Hours
Calibration Lanes	1.96
Mine Test Grid	0.72

3.3 TEST CONDITIONS

3.3.1 Weather Conditions

An ATC weather station located approximately 2 miles west of the test site was used to record average temperature and precipitation on an hourly basis for each day of operation. The temperatures listed in Table 4 represent the average temperature during field operations from 0700 through 1700 hours while the precipitation data represents a daily total amount of rainfall. Hourly weather logs used to generate this summary are provided in Appendix B.

TABLE 4. TEMPERATURE/PRECIPITATION DATA SUMMARY

Date, 2002	Average Temperature, °F	Total Daily Precipitation, in.
2 December	38.6	0.00
3 December	25.0	0.00

3.3.2 Field Conditions

The Calibration Lane was surveyed on 2 December 2002. The Mine Grid was completed on 3 December 2002. The grids were muddy throughout the survey due to rain prior to testing.

3.3.3 Soil Moisture

The soil moisture logs are included in Appendix C. Three soil probes were placed at various locations of the site to capture soil moisture data: open field, open field lowland (wet) and open field scenario No. 1 wooded area. Measurements were collected in percent moisture and were taken twice daily (morning and afternoon) from five different soil layers (0 to 6 in., 6 to 12 in., 12 to 24 in., 24 to 36 in. and 36 to 48 in.) from each probe.

The soil moisture data collected are summarized in Table 5. The average moisture content was calculated by averaging the morning and afternoon measurements for each layer of each probe for the duration of the field operations.

TABLE 5. SOIL MOISTURE DATA SUMMARY

Layer, in.	Average Moisture Content, %	Standard Deviation, %
OPEN FIELD PROBE		
0 to 6	12.40	2.45
6 to 12	4.43	5.08
12 to 24	6.87	3.71
24 to 36	20.80	2.38
36 to 48	28.30	2.95

3.4 FIELD ACTIVITIES

3.4.1 Setup/Mobilization

These activities included initial mobilization and daily equipment preparation and breakdown. The three-man crew took 1 hour and 34 minutes on 2 December 2002 to perform the initial setup and mobilization. On 3 December 2002, 25 minutes was spent setting up the equipment.

3.4.2 Calibration

The demonstrator spent 1 hour and 43 minutes in the calibration lanes. No calibration activities were conducted while operating in the Mine Grid.

3.4.3 Downtime Occasions

Occasions of downtime are grouped into five categories: equipment/data checks or equipment maintenance, equipment failure and repair, weather, Demonstration Site issues, or breaks/lunch. All downtime is included for the purposes of calculating labor costs (section 5) except for downtime due to Demonstration Site issues. Demonstration Site issues, while noted in the Daily Log, are considered nonchargeable downtime for the purposes of calculating labor costs and are not discussed. Breaks and lunches are not discussed either.

3.4.3.1 Equipment/data checks, maintenance.

Data and equipment checks amounted to a total of 12 minutes while surveying the Mine Grid.

3.4.3.2 Equipment failure or repair.

No equipment failure or repairs were conducted while surveying in the Mine Grid.

3.4.3.3 Weather.

No delays occurred due to weather.

3.4.4 Data Collection

The demonstrators spent 31 minutes collecting data in the Mine Grid. This time excludes break/lunches and downtimes as described in section 3.4.3.

3.4.5 Demobilization

It took the three-man crew 1 hour to break down and pack equipment for demobilization.

3.5 PROCESSING TIME

The raw data was submitted the last day of testing. Witten processed their data for scoring within the 30 day time period.

3.6 DEMONSTRATOR'S FIELD PERSONNEL

Survey crew:
- Operations Manager: Tony DeRubeis
- Field Engineers: Andrew Thomas
- Quality Assurance: Michael Oristaglio

Processing and interpretation:
- Data Processing Manager: Robert Casadonte
- CAD Engineer: Richard Stearns
- Scientific support: Ralf Birken*, Ross Deming, Thorkild Hansen*
- Quality Assurance: Ross Deming

*Foreign national, no access to APG site needed.

3.7 DEMONSTRATOR'S FIELD SURVEYING METHOD

Witten began surveying in the northeast corner of the calibration lane continuing in a north/south direction. They also surveyed the Mine Grid starting both in the northeast corner and surveying in an east/west direction. They utilized ultra-wideband impulse radar and laser theodolite to cover and collect data for all of the grid areas.

3.8 SUMMARY OF DAILY LOGS

No significant events occurred while surveying the Mine Grid.

SECTION 4. TECHNICAL PERFORMANCE RESULTS

4.1 ROC CURVES FOR STANDARDIZED INERT MINE TARGETS

Figure 2 shows the probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive. Figure 3 shows both probabilities plotted against their respective probability of background alarm. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

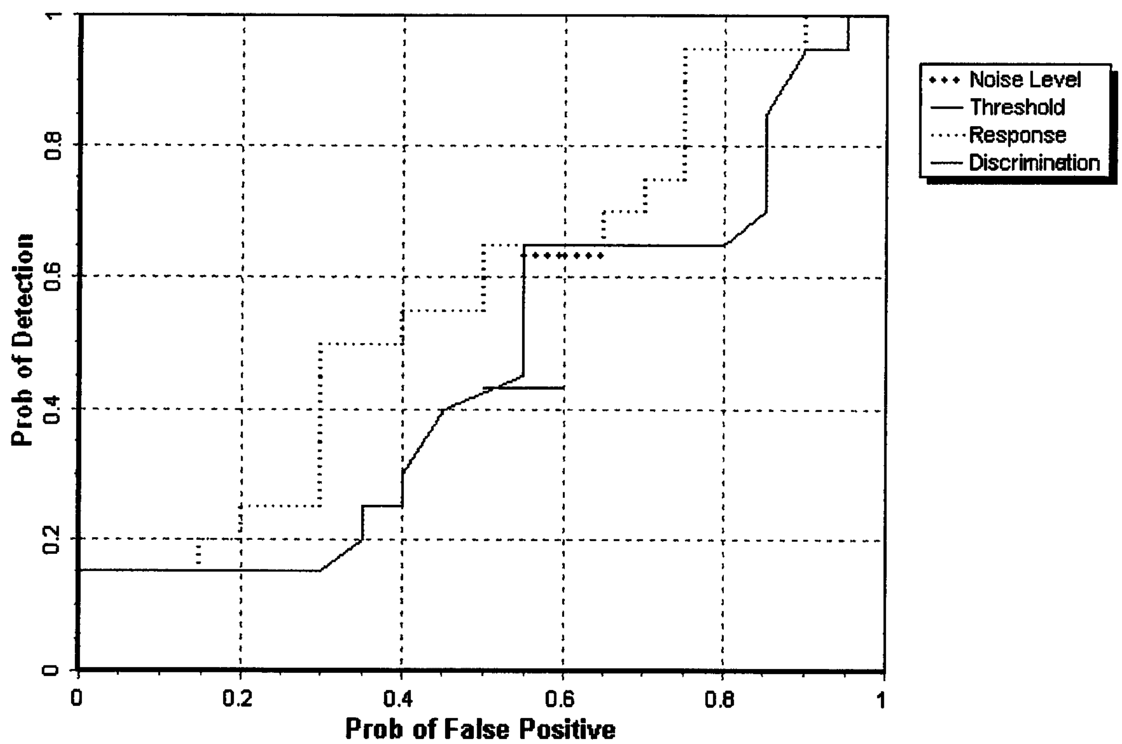

Figure 2. Mine Grid probability of detection for response and discrimination stages versus their respective probability of false positive.

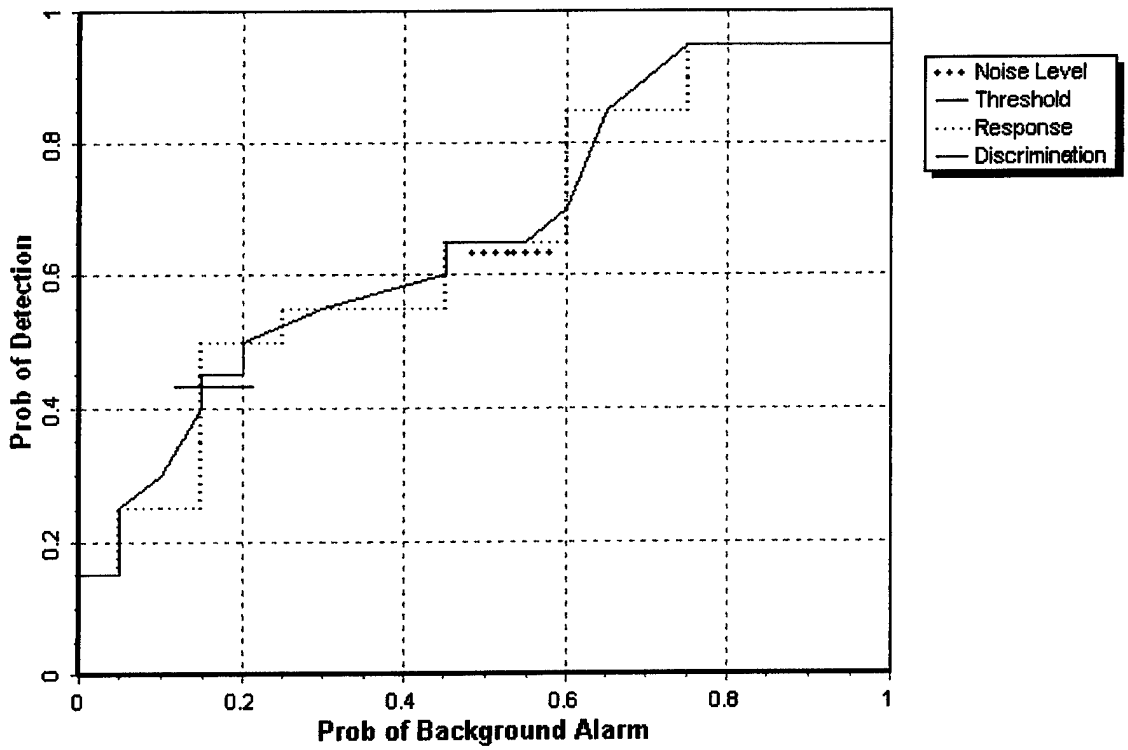

Figure 3. Mine Grid probability of detection for response and discrimination stages versus their respective probability of background alarm.

4.2 PERFORMANCE SUMMARIES

Results for the Mine Grid test are presented in Table 6. (For cost results, see section 5.) Results by size and depth include both standard and nonstandard ordnance. The results are relative to the number of mines emplaced.

The RESPONSE STAGE results are derived from the list of anomalies above the demonstrator-provided noise level. The results for the DISCRIMINATION STAGE are derived from the demonstrator's recommended threshold for optimizing UXO field cleanup by minimizing false digs and maximizing mine recovery. The lower 90-percent confidence limit on probability of detection and probability of false positive was calculated assuming that the number of detections and false positives are binomially distributed random variables. All results in Table 6 have been rounded to protect the ground truth. However, lower confidence limits were calculated using actual results.

TABLE 6. SUMMARY OF MINE GRID RESULTS

Metric	Overall
RESPONSE STAGE	
P_d	0.65
P_d Lower 90% Confidence Level	0.50
P_{fp}	0.65
P_{fp} Lower 90%Confidence Level	0.54
P_{ba}	0.45
DISCRIMINATION STAGE	
P_d	0.45
P_d Lower 90% Confidence Level	0.31
P_{fp}	0.55
P_{fp} Lower 90% Confidence Level	0.46
P_{ba}	0.15

Response Stage Noise Level: 13.00
Recommended Discrimination Stage Threshold: 53.00

Note: The response stage noise level and recommended discrimination stage threshold values are provided by the demonstrator.

4.3 EFFICIENCY, REJECTION RATES, AND TYPE CLASSIFICATION

Efficiency and rejection rates are calculated to quantify the discrimination ability at specific points of interest on the ROC curve: (1) at the point where no decrease in P_d is suffered (i.e., the efficiency is by definition equal to one) and (2) at the operator selected threshold. These values are reported in Table 7.

TABLE 7. EFFICIENCY AND REJECTION RATES

	Efficiency (E)	False Positive Rejection Rate	Background Alarm Rejection Rate
At Operating Point	0.68	0.12	0.71
With No Loss of P_d	1.00	0.08	0.07

4.4 LOCATION ACCURACY

The mean location error and standard deviations appear in Table 8. These calculations are based on average missed depth for ordnance correctly identified in the discrimination stage. Depths are measured from the closest point of the ordnance to the surface. For the Mine Grid, only depth errors are calculated, since (x, y) positions are known to be the centers of each grid square.

TABLE 8. MEAN LOCATION ERROR AND STANDARD DEVIATION (M)

	Mean	Standard Deviation
Depth	0.08	0.08

SECTION 5. ON-SITE LABOR COSTS

A standardized estimate for labor costs associated with this effort was calculated as follows: the first person at the test site was designated "supervisor", the second person was designated "data analyst", and the third and following personnel were considered "field support". Standardized hourly labor rates were charged by title: supervisor at $95.00/hour, data analyst at $57.00/hour, and field support at $28.50/hour.

Government representatives monitored on-site activity. All on-site activities were grouped into one of ten categories: initial setup/mobilization, daily setup/stop, calibration, collecting data, downtime due to break/lunch, downtime due to equipment failure, downtime due to equipment/data checks or maintenance, downtime due to weather, downtime due to demonstration site issue, or demobilization. See Appendix D for the daily activity log. See section 3.4 for a summary of field activities.

The standardized cost estimate associated with the labor needed to perform the field activities is presented in Table 9. Note that calibration time includes time spent in the calibration lanes as well as field calibrations. "Site survey time" includes daily setup/stop time, collecting data, breaks/lunch, downtime due to equipment/data checks or maintenance, downtime due to failure, and downtime due to weather.

TABLE 9. ON-SITE LABOR COSTS

	No. People	Hourly Wage	Hours	Cost
INITIAL SETUP				
Supervisor	1	$95.00	1.56	$148.20
Data Analyst	1	57.00	1.56	88.92
Field Support	1	28.50	1.56	4.46
Subtotal				**$281.58**
CALIBRATION				
Supervisor	1	$95.00	1.96	$186.20
Data Analyst	1	57.00	1.96	111.72
Field Support	1	28.50	1.96	55.86
Subtotal				**$353.78**
SITE SURVEY				
Supervisor	1	$95.00	0.72	$68.40
Data Analyst	1	57.00	0.72	41.04
Field Support	1	28.50	0.72	20.52
Subtotal				**$129.96**

See notes at end of table.

TABLE 9 (CONT'D)

	No. People	Hourly Wage	Hours	Cost
DEMOBILIZATION				
Supervisor	1	$95.00	1.00	$95.00
Data Analyst	1	57.00	1.00	57.00
Field Support	1	28.50	1.00	28.50
Subtotal				**$180.50**
TOTAL				**$945.82**

Notes: Calibration time includes time spent in the calibration lanes as well as calibration before each data run.

Site Survey time includes daily setup/stop time, collecting data, breaks/lunch, downtime due to system maintenance, failure, and weather.

SECTION 6. COMPARISON OF RESULTS TO DATE

No comparisons to date.

SECTION 7. APPENDIXES

APPENDIX A. TERMS AND DEFINITIONS

GENERAL DEFINITIONS

Anomaly: Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

Detection: An anomaly location that is within R_{halo} of an emplaced ordnance item.

Emplaced Ordnance: An ordnance item buried by the government at a specified location in the test site.

Emplaced Clutter: A clutter item (i.e., nonordnance item) buried by the government at a specified location in the test site.

R_{halo}: A predetermined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. If multiple declarations lie within R_{halo} of any item (clutter or ordnance), the declaration with the highest signal output within the R_{halo} will be utilized. For the purpose of this program, a circular halo 0.5 meter in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meter in length. When ordnance items are longer than 0.6 meter, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the length of the ordnance plus 1 meter.

Small Ordnance: Caliber of ordnance less than or equal to 40 mm (includes 20-mm projectile, 40-mm projectile, submunitions BLU-26, BLU-63, and M42).

Medium Ordnance: Caliber of ordnance greater than 40 mm and less than or equal to 81 mm (includes 57-mm projectile, 60-mm mortar, 2.75-in. Rocket, MK118 Rockeye, 81-mm mortar).

Large Ordnance: Caliber of ordnance greater than 81 mm (includes 105-mm HEAT, 105-mm projectile, 155-mm projectile, 500 pound bomb).

Shallow: Items buried less than 0.3 meter below ground surface.

Medium: Items buried greater than or equal to 0.3 meter and less than 1 meter below ground surface.

Deep: Items buried greater than or equal to 1 meter below ground surface.

Response Stage Noise Level: The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the Blind Grid and/or Mine Grid Test area.

Discrimination Stage Threshold: The demonstrator selected threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

Binomially Distributed Random Variable: A random variable of the type which has only two possible outcomes, say success and failure, is repeated for n independent trials with the probability p of success and the probability 1-p of failure being the same for each trial. The number of successes x observed in the n trials is an estimate of p and is considered to be a binomially distributed random variable.

RESPONSE AND DISCRIMINATION STAGE DATA

The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver-operating characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}) and those that do not correspond to any known item, termed background alarms.

The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the RESPONSE STAGE, the demonstrator provides the scoring committee with the location and signal strength of all anomalies that the demonstrator has deemed sufficient to warrant further investigation and/or processing as potential emplaced ordnance items. This list is generated with minimal processing (e.g., this list will include all signals above the system noise threshold). As such, it represents the most inclusive list of anomalies.

The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such, and to reject clutter. For the same locations as in the RESPONSE STAGE anomaly list, the DISCRIMINATION STAGE list contains the output of the algorithms applied in the discrimination-stage processing. This list is prioritized based on the demonstrator's determination that an anomaly location is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For electronic signal processing, priority ranking is based on algorithm output. For other systems, priority ranking is based on human judgment. The demonstrator also selects the threshold that the demonstrator believes will provide "optimum" system performance, (i.e., that retains all the detected ordnance and rejects the maximum amount of clutter).

Note: The two lists provided by the demonstrator contain identical numbers of potential target locations. They differ only in the priority ranking of the declarations.

RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection (P_d^{res}): P_d^{res} = (No. of response-stage detections)/(No.of emplaced ordnance in the test site).

Response Stage False Positive (fp^{res}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Response Stage Probability of False Positive (P_{fp}^{res}): P_{fp}^{res} = (No. of response-stage false positives)/(No. of emplaced clutter items).

Response Stage Background Alarm (ba^{res}): An anomaly in a Blind Grid and/or Mine Grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm (P_{ba}^{res}): Blind Grid and/or Mine Grid only: P_{ba}^{res} = (No. of response-stage background alarms)/(No. of empty grid locations).

Response Stage Background Alarm Rate (BAR^{res}): Open Field only: BAR^{res} = (No. of response-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{res}, P_{fp}^{res}, P_{ba}^{res}, and BAR^{res} are functions of t^{res}, the threshold applied to the response-stage signal strength. These quantities can therefore be written as $P_d^{res}(t^{res})$, $P_{fp}^{res}(t^{res})$, $P_{ba}^{res}(t^{res})$, and $BAR^{res}(t^{res})$.

DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to nonordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection (P_d^{disc}): P_d^{disc} = (No. of discrimination-stage detections)/(No. of emplaced ordnance in the test site).

Discrimination Stage False Positive (fp^{disc}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Discrimination Stage Probability of False Positive (P_{fp}^{disc}): P_{fp}^{disc} = (No. of discrimination stage false positives)/(No. of emplaced clutter items).

Discrimination Stage Background Alarm (ba^{disc}): An anomaly in a Blind Grid and/or Mine Grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm (P_{ba}^{disc}): P_{ba}^{disc} = (No. of discrimination-stage background alarms)/(No. of empty grid locations).

Discrimination Stage Background Alarm Rate (BAR^{disc}): BAR^{disc} = (No. of discrimination-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{disc}, P_{fp}^{disc}, P_{ba}^{disc}, and BAR^{disc} are functions of t^{disc}, the threshold applied to the discrimination-stage signal strength. These quantities can therefore be written as $P_d^{disc}(t^{disc})$, $P_{fp}^{disc}(t^{disc})$, $P_{ba}^{disc}(t^{disc})$, and $BAR^{disc}(t^{disc})$.

RECEIVER-OPERATING CHARACERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed based on the above definitions. The ROC curves plot the relationship between P_d versus P_{fp} and P_d versus BAR or P_{ba} as the threshold applied to the signal strength is varied from its minimum (t_{min}) to its maximum (t_{max}) value.[1] Figure A-1 shows how P_d versus P_{fp} and P_d versus BAR are combined into ROC curves. Note that the "res" and "disc" superscripts have been suppressed from all the variables for clarity.

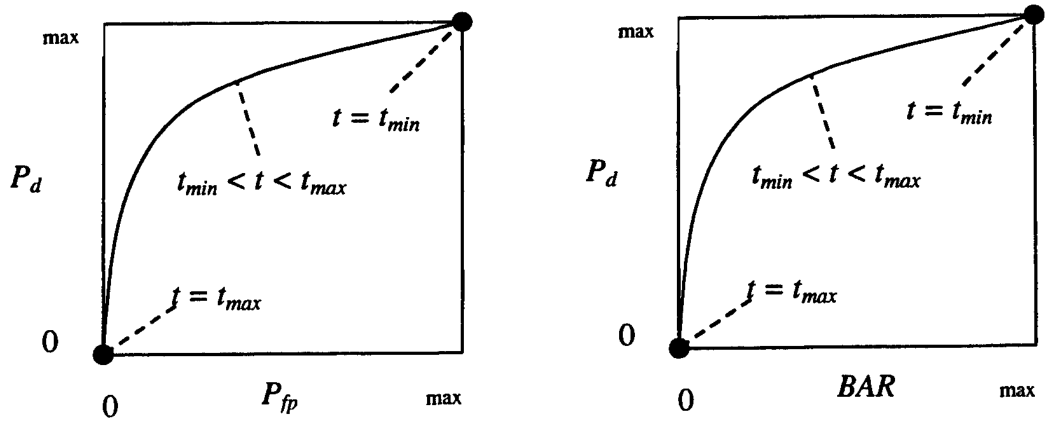

Figure A-1. ROC curves for open-field testing. Each curve applies to both the response and discrimination stages.

[1]Strictly speaking, ROC curves plot the P_d versus P_{ba} over a predetermined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an open field scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the open field ROC curves do not have information from low signal-output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the Blind Grid and/or Mine Grid Test sites are true ROC curves.

METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from nonordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E): $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$; Measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage tmin) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

False Positive Rejection Rate (R_{fp}): $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$; Measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage tmin). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate (R_{ba}):

BLIND GRID and/or MINE GRID: $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$.
OPEN FIELD: $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})])$.

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

APPENDIX B. DAILY WEATHER LOGS

TABLE B-1. WEATHER LOG

DCP 7 Data from Phillips Airfield							
Date	Time, EDST	Average Temperature, °F	Maximum Temperature, °F	Minimum Temperature, °F	RH, %	Station Pressure, in. Hg	Precipitation, in.
12/2/2002	02:00	22.9	25.6	21.7	77	29.96	0.00
12/2/2002	03:00	28.8	31.8	25.3	71	29.96	0.00
12/2/2002	04:00	31.4	32.2	30.3	58	29.95	0.00
12/2/2002	05:00	29.9	31.1	28.9	60	29.95	0.00
12/2/2002	06:00	29.2	29.9	28.4	61	29.95	0.00
12/2/2002	07:00	29.5	30.1	28.8	61	29.95	0.00
12/2/2002	08:00	30.1	33.3	27.8	66	29.96	0.00
12/2/2002	09:00	33.8	35.5	33.0	57	29.96	0.00
12/2/2002	10:00	35.9	37.5	34.9	52	29.96	0.00
12/2/2002	11:00	38.6	39.9	37.1	45	29.95	0.00
12/2/2002	12:00	40.6	41.6	39.4	45	29.92	0.00
12/2/2002	13:00	42.6	44.1	41.3	43	29.88	0.00
12/2/2002	14:00	44.1	44.8	43.4	40	29.85	0.00
12/2/2002	15:00	43.6	44.2	43.1	43	29.83	0.00
12/2/2002	16:00	43.2	44.1	42.5	47	29.81	0.00
12/2/2002	17:00	43.1	43.5	42.6	44	29.80	0.00
12/2/2002	18:00	42.7	43.4	41.6	45	29.79	0.00
12/2/2002	19:00	41.6	42.6	39.9	48	29.80	0.00
12/2/2002	20:00	40.8	41.3	39.9	51	29.79	0.00
12/2/2002	21:00	38.3	40.9	36.9	60	29.79	0.00
12/2/2002	22:00	37.6	38.7	36.3	64	29.79	0.00
12/2/2002	23:00	37.1	38.5	35.8	66	29.80	0.00
12/2/2002	23:59	39.0	41.1	37.1	59	29.83	0.00
12/3/2002	01:00	40.1	40.7	39.4	46	29.86	0.00
12/3/2002	02:00	39.0	39.7	38.3	49	29.89	0.00
12/3/2002	03:00	35.9	38.9	32.3	64	29.95	0.00
12/3/2002	04:00	31.1	32.6	29.8	62	30.01	0.00
12/3/2002	05:00	28.6	30.1	26.8	56	30.06	0.00
12/3/2002	06:00	25.8	27.1	24.7	55	30.11	0.00
12/3/2002	07:00	23.7	24.9	22.7	48	30.17	0.00
12/3/2002	08:00	22.6	23.0	22.2	43	30.23	0.00
12/3/2002	09:00	22.8	23.3	22.2	31	30.28	0.00
12/3/2002	10:00	22.9	23.5	22.4	31	30.32	0.00
12/3/2002	11:00	23.5	24.5	22.7	34	30.35	0.00
12/3/2002	12:00	24.6	25.8	23.9	35	30.35	0.00
12/3/2002	13:00	25.8	27.0	24.9	35	30.35	0.00
12/3/2002	14:00	27.0	27.7	26.4	33	30.35	0.00
12/3/2002	15:00	27.8	28.5	27.2	32	30.36	0.00
12/3/2002	16:00	27.7	28.3	27.3	32	30.37	0.00
12/3/2002	17:00	26.6	27.6	25.4	33	30.39	0.00
12/3/2002	18:00	25.1	25.6	24.2	35	30.41	0.00
12/3/2002	19:00	24.2	24.6	23.6	36	30.41	0.00
12/3/2002	20:00	22.6	24.0	21.5	41	30.43	0.00
12/3/2002	21:00	20.3	22.1	18.0	46	30.44	0.00

TABLE B-1 (CONT'D)

DCP 7 Data from Phillips Airfield							
Date	Time, EDST	Average Temperature, °F	Maximum Temperature, °F	Minimum Temperature, °F	RH, %	Station Pressure, in. Hg	Precipitation, in.
12/3/2002	22:00	18.9	20.4	17.3	56	30.45	0.00
12/3/2002	23:00	18.6	19.5	17.7	56	30.46	0.00
12/3/2002	23:59	17.6	18.7	16.1	63	30.47	0.00

APPENDIX C. SOIL MOISTURE

UXO SOIL MOISTURE PROBES DATA
12/10/2002

Rec#: 53

1. Item ID (Vender) WITTEN   2. Date: 12/02/2002

3. Start Time: 1106   4. Stop Time 1415

5. Data Collectors Name JOYCE E HASPERT

-------------------- REPEAT SECTION --------------------

	Morning % Moisture	Afternoon % Moisture
Wet Area	Time: 1125	Time: 1415
1	39.5	39.5
2	11.1	7.8
3	42.6	46.5
4	4.5	4.5
5	4.6	4.6
Tree Area	Time: 1116	Time: 1405
1	51.4	31.3
2	62.2	57.9
3	40.6	38.4
4	0.4	2.6
5	3.0	35.3
Other Area	Time: 1106	Time: 1355
1	12.5	9.9
2	1.7	10.3
3	8.7	2.6
4	23.5	19.9
5	31.5	26.0

UXO SOIL MOISTURE PROBES DATA

Rec#: 54

1. Item ID (Vender) WITTEN   2. Date: 12/03/2002

3. Start Time: 1107   4. Stop Time 1123

5. Data Collectors Name JOYCE E HASPERT

-------------------- REPEAT SECTION --------------------

	Morning % Moisture		Afternoon % Moisture	
Wet Area	Time:	1123	Time:	0
1		76.7		0.0
2		67.6		0.0
3		74.2		0.0
4		64.4		0.0
5		52.2		0.0
Tree Area	Time:	1116	Time:	0
1		24.4		0.0
2		28.8		0.0
3		29.6		0.0
4		11.7		0.0
5		44.0		0.0
Other Area	Time:	1107	Time:	0
1		14.8		0.0
2		1.3		0.0
3		9.3		0.0
4		19.0		0.0
5		26.9		0.0

APPENDIX D. DAILY ACTIVITY LOGS

Date	No. of People	Area-Tested	Status Start Time	Status Stop Time	Duration min.	Operational Status	Operational Status - Comments	Track Method	Track Method=Other Explain	Pattern	Field Conditions	
12/2/2002	3	CALIBRATION LANES	928	930	2	INITIAL SET-UP	INSTALLED ELECTRICAL UNIT	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	930	936	6	INITIAL SET-UP	STARTED JOHN DEERE TRACTOR	OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	936	938	2	INITIAL SET-UP	UNHOOKED STRAPS JOHN DEERE TRACTOR	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	938	939	1	INITIAL SET-UP	REMOVE RAMPS TO DISLODGE JOHN DEERE TRACTOR	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	939	944	5	INITIAL SET-UP	CONNECT ELECTRONIC SYSTEM TO JOHN DEERE TRACTOR	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	944	945	1	INITIAL SET-UP	ATTACHED WATER SOLVENT SPRAY CANS TO JOHN DEERE TRACTOR	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	945	1003	18	INITIAL SET-UP	NO ACTION	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	1003	1053	50	INITIAL SET-UP	SETTING UP SURVEYING EQUIPMENT	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	1053	1054	1	INITIAL SET-UP	REMOVE JOHN DEERE TRACTOR FROM TRAILER	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	1054	1102	8	INITIAL SET-UP	PREPARE FOR FIRST RUN OF OPERATION	OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	1102	1235	93	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	LINEA R	CLEAR/UNLIMITED	DRY
12/2/2002	3	CALIBRATION LANES	1235	1300	25	DOWNTIME DUE TO EQUIP MAINT/CHECK	DATA CHECK WAS COMPLETED	OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	BLIND TEST GRID	1300	1330	30	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	LINEA R	CLEAR/UNLIMITED	DRY
12/2/2002	3	BLIND TEST GRID	1330	1350	20	DOWNTIME DUE TO EQUIP MAINT/CHECK	JOHN DEERE TRACTOR STUCK IN DITCH	OTHER	NA	NA	CLEAR/UNLIMITED	DUSTY

Date	No. of People	Area-Tested	Status Start Time	Status Stop Time	Duration min.	Operational Status	Operational Status - Comments	Track Method	Track Method=Other Explain	Pattern	Field Conditions	
12/2/2002	3	BLIND TEST GRID	1350	1410	20	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	LINEAR	CLEAR/UNLIMITED	DRY
12/2/2002	3	MINE GRID	1410	1416	6	DOWNTIME DUE TO EQUIP MAINT/CHECK		OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	MINE GRID	1416	1434	18	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	LINEAR	CLEAR/UNLIMITED	DRY
12/2/2002	3	BLIND TEST GRID	1434	1440	6	DOWNTIME DUE TO EQUIP MAINT/CHECK		OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/2/2002	3	BLIND TEST GRID	1440	1509	29	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	CROSSHATCH	CLEAR/UNLIMITED	DRY
12/2/2002	3	BLIND TEST GRID	1509	1545	36	DAILY START, STOP	END OF DAILY OPERATIONS	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/3/2002	3	BLIND TEST GRID	920	1005	45	DAILY START, STOP	START OF DAILY OPERATIONS / EQUIPMENT SET-UP	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/3/2002	3	BLIND TEST GRID	1005	1019	14	BREAK/LUNCH	BREAK	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/3/2002	3	BLIND TEST GRID	1019	1045	26	DOWNTIME DUE TO EQUIP MAINT/CHECK	USING SURVEYING EQUIPMENT	OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/3/2002	3	BLIND TEST GRID	1042	1043	1	DOWNTIME DUE TO EQUIP MAINT/CHECK	REPLACED WATER SOLVENT SPRAY PAINT ON JOHN DEERE TRACTOR	OTHER	NA	NA	CLEAR/UNLIMITED	DRY
12/3/2002	3	BLIND TEST GRID	1045	1224	99	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	LINEAR	CLEAR/UNLIMITED	DRY
12/3/2002	3	MINE GRID	1224	1230	6	DOWNTIME DUE TO EQUIP MAINT/CHECK		OTHER	SURVEY EQUIPMENT	NA	CLEAR/UNLIMITED	DRY
12/3/2002	3	MINE GRID	1230	1243	13	COLLECTING DATA		OTHER	SURVEY EQUIPMENT	LINEAR	CLEAR/UNLIMITED	DRY
12/3/2002	3	BLIND TEST GRID	1243	1343	60	DEMOBILIZATION	END OF OPERATIONS	OTHER	NA	NA	CLEAR/UNLIMITED	DRY

APPENDIX E. REFERENCES

1. Standardized UXO Technology Demonstration Site Handbook, DTC Project No. 8-CO-160-000-473, Report No. ATC-8349, March 2002.

2. Aberdeen Proving Ground Soil Survey Report, October 1998.

3. Data Summary, UXO Standardized Test Site: APG Soils Description, May 2002.

APPENDIX F. ABBREVIATIONS

AEC	=	U.S. Army Environmental Center
APG	=	Aberdeen Proving Ground
ATC	=	U.S. Army Aberdeen Test Center
CAD	=	computer-aided design
ERDC	=	U.S. Army Corp of Engineers Engineering, Research and Development Center
ESTCP	=	Environmental Security Technology Certification Program
EQT	=	Army Environmental Quality Technology Program
GPR	=	ground-penetrating radar
GPS	=	Global Positioning System
GX	=	Geosoft executable
HH	=	handheld
MS	=	Microsoft
POC	=	point of contact
PVC	=	polyvinyl chloride
QC	=	quality control
ROC	=	receiver-operating characteristic
RTK	=	real time kinematic
SAR	=	synthetic-aperture radar
SERDP	=	Strategic Environmental Research and Development Program
UXO	=	unexploded ordnance

APPENDIX G. DISTRIBUTION LIST

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